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ABSTRACT

The article presents the methods proposed by the authors for measuring direct solar radiation, total solar radiation, reflected radiation and the radiation balance at sea. An evaluation is given of the accuracy of actinometric measurements from ships.

Although seas and oceans occupy a large part of the earth's surface, their radiation state has not been studied sufficiently. One of the reasons is the difficulty of measuring the radiation balance and its components from ships.

Episodic actinometric observations have been performed by various ships for a period of 30 - 40 years; however, to date there is no single method for making actinometric measurements at sea.

Various observers use different measuring techniques: some install the boom at the bottom of the ship, others on board and some even at the stern.

In a whole series of cases, the results of the measurements are made worthless by substantial errors in the methods (large shading or illumination of devices by the ship's superstructure, insufficient length of the boom with respect to the height of the shipboard above the water, and others).

The purpose of our work is to use the available actinometric measurements at sea, and also the results of experimental and methodical investigations to develop one method for carrying out actinometric measurements from ships at sea.

As a basis for this, we use the results of methodical investigations carried out in 1960-1961 on expedition ships "Yu. M. Shokal'skiy" and "A. I. Voyeykov" and in 1962 on the expedition ship "Gidorzond," and the experience accumulated in the course of many years during actinometric measurements from small boats, as well as a whole series of additional experimental and theoretical investigations conducted by us.

As a result of these investigations, we recommend that the following actinometric measurements be made from ships:

(1) measurement of direct solar radiation;
(2) measurement of total radiation;
(3) measurement of reflected radiation;
(4) measurement of the radiation balance.

We have decided not to use a pyranometer, shaded from solar radiation, to measure scattered radiation, because these methods are not sufficiently accurate when the ship rolls.

Scattered radiation is determined as the difference between total radiation and direct radiation computed on a horizontal surface:

$$D = Q - S'.$$

The direct radiation is measured by means of a thermoelectric actinometer installed on a Cardan's table at the upper bridge. The direction of the actinometer towards the sun is done manually.

Total Radiation

Total radiation is the basic component of the radiation balance; therefore, in carrying out actinometric observations at sea, it is important to know how to measure the magnitude of total radiation accurately, not only during a period of calm, but also when the sea is rough.

As we know, in measuring total radiation under conditions on land, the following method is used: A pyranometer, shaded from direct solar radiation, is used to measure scattered radiation D; an actinometer is used to measure direct solar radiation S on a perpendicular surface.

Total radiation is computed by taking into account the altitude of the sun above the horizon in the following manner:

$$Q = S \sin h_{\odot} + D.$$

Because during the actinometric measurements at sea the measurement of scattered radiation becomes difficult and is not very accurate, we have investigated the question of the reliability that can be achieved when measuring total radiation by means of an unshaded pyranometer.

The parallel measurements of total radiation using the "dry land" technique and using an unshaded pyranometer produced the following results: when the ship rolls, the errors in the measurement of total radiation using a pyranometer on the average constitute 4 percent; however, in a series of cases (when $h_{\odot}$ are small) these errors reach values of 8-9 percent.

The results of similar comparisons at the Karadaga Observatory have shown that when the ship is not rolling, these errors in measurement are somewhat lower, and for small $h_{\odot}$ do not exceed 5-6 percent.

On this basis we feel that it is possible to measure total radiation from ships by means of a pyranometer without shading it from direct solar radiation.

Let us consider the question as to where the pyranometer should be placed on the ship, so that the measurement errors are minimum.

On the expedition ship "Gidrozond" in 1962 we carried out simultaneous measurements of total radiation at various points on the ship: at the upper end of the focslemast, (Q_1), at the upper end of the mizzenmast (Q_2) and at the upper bridge (Q_3). Table 1 shows the results of these measurements.

TABLE 1.

$h_{\odot}$ degree	33.2	38.8	39.9	41.3	37.0	11.0	28.4	43.0	37.2	21.0	15.2	12.8
Q_1 cal/cm^2 min	0.71	0.58	0.72	0.68	0.79	0.03	0.05	0.51	0.84	0.60	0.27	0.06
Q_2 cal/cm^2 min	0.70	0.58	0.71	0.70	0.80	0.03	0.05	0.51	0.87	0.60	0.30	0.06
Q_3 cal/cm^2 min	0.72	0.52	0.60	0.66	0.70	0.03	0.05	0.52	0.78	0.58	0.28	0.05

We can see from the table that the values of total radiation obtained by means of pyranometers placed at the top of the focslemast and the mizzenmast are sufficiently close to each other (the discrepancy does not exceed 3-4 percent).

The values of total radiation (Q_3) in a series of cases, principally for $h_{\odot} > 30^{\circ}$, differ substantially from the quantities Q_1 and Q_2, which is explained by the fact that for the stated altitudes of the sun the pyranometer was shaded by various parts of the mast.

All these facts show that it was most rational to place the pyranometer at the upper end of the mast where it is not shaded by anything. In this case it is recommended that a special device be used, a hoist which can be used to lower and raise the pyranometer at any time. The hoist consists of two principal parts: a cantilever 1, fixed at the top of the mast, and a movable carriage 2 with the device (fig. 1). The carriage with the device is pulled up and down by a pulley fixed to the cantilever.

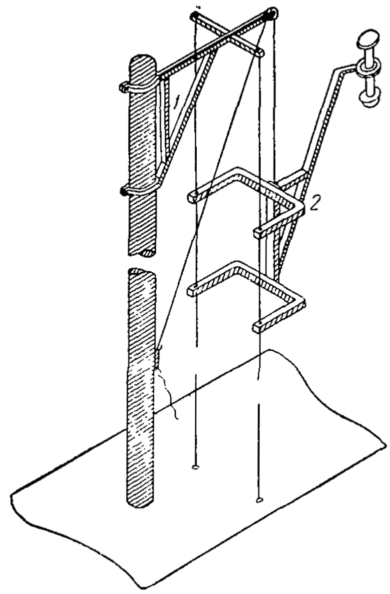

Figure 1. "Hoist" for pyranometer.

The general view of the pyranometer fixed by means of the hoist at the top of the mast on the expedition ship "Gidrozond" is shown in figure 2.

Because a pyranometer with a conventional Cardan's suspension retains the horizontal position of the sensing surface with sufficient reliability only up to a wind velocity of 10-15 m/sec, while for a large wind velocity there is displacement of the pyranometer from the horizontal position, it is rational to use a Cardan's suspension with an additional headpiece to eliminate the effect of wind. This headpiece in its shape and size corresponds to the pyranometer (fig. 3).

The testing of a pyranometer with this type of Cardan's suspension has shown that even when the wind is 35-40 m/sec, there is no noticeable deviation of the pyranometer from a horizontal position. In this connection it is necessary to point out that experimental investigations determined that the period of oscillations of the Cardan's suspension with a headpiece of this type is less than 1 sec, i.e., much less than the period of oscillation of the ship.

In carrying out actinometric observations at sea, it is necessary to make sure that the pyranometer is in a strictly horizontal position, because its deviation from a horizontal position may lead to substantial errors when the $h_{\odot}$ are small.

Table 2 shows the errors which we have computed (in percent) when measuring Q for various $h_{\odot}$, and for deviations of the pyranometer from a horizontal position by 0.5-3°. We should note in this connection that when the ship rolls the Cardan's suspensions do not provide for a strictly horizontal position; for this reason, in order to carry out actinometric measurements at sea, we must observe the operation of Cardan's suspensions and grease them systematically.

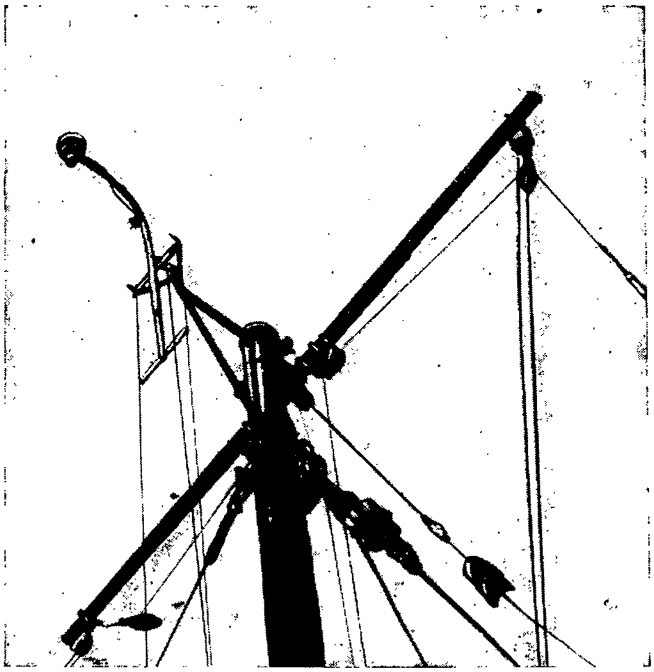

Figure 2. General view of pyranometer installed on the mast of expedition ship "Gidrozond."

Because a pyranometer under conditions at sea cannot always turn a specific side to the sun, the protective glasses must be selected with special care so that they are equal over the entire azimuth and have a small correction factor F_h.

TABLE 2.

α^o	$h^o_\odot$					
	5	10	20	30	50	70
0.5	5	4	2	1	0.6	0.5
1	10	8	4	2	1	1
3	29	20	11	8	4	3

It is necessary to keep track of the cleanliness of the glass cap. When splashes of sea water or raindrops or dew fall on the pyranometer glass, its measurements decrease basically by 1-2 percent, but when the $h_\odot$ are small, the observed decrease in radiation may be 5-6 percent.

In measuring total radiation from ships, it is rational to use the M-91 galvanometer or the EPP-09 potentiometer, which are very stable with respect to rolling. When GSA-1 is used (which is extremely undesirable), it is necessary to switch the galvanometer, for small values of $h_{\odot}$ to the terminals +p, which provide for higher sensitivity of the galvanometer.

To achieve maximum accuracy in measuring total radiation under conditions of calm or when waves are small, it is necessary to make not less than 6 readings with the galvanometer. When the rolling of the ship is severe, 10 galvanometer readings are necessary. The necessity for such a large number of readings is explained by the fact that during the rolling of the ship the pyronometer itself may be rocked on its Cardan's suspension. Special investigations have shown that this may cause values of $\frac{dQ}{Q}$ of 7-8 percent, while the variation in $\frac{dQ}{Q}$ as a function of $h_{\odot}$ could not be traced.

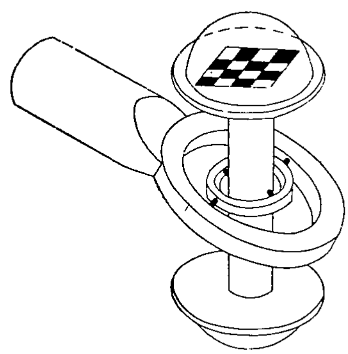

Figure 3. Cardan's suspension with an auxiliary headpiece.

If the practical recommendations proposed by us are carried out, total radiation under conditions at sea may be measured by means of the M-91 Galvonometer with errors not exceeding 5-7 percent for large $h_{\odot}$ and 10-15 percent for small $h_{\odot}$.

Reflection Radiation and the Albedo of the Sea

To investigate the thermal state of the sea, it is important to determine the magnitude of radiation reflected from the surface of the sea. As we know, various observers install the boom with the albedometer in various ways: at the bow, at the stern, and from board. It turns out that in a series of cases the results of measurements were worthless because of large errors in measurements (the shading or illumination from the body of the ship, the effect of breakers, foam, etc.).

An investigation of the possible systematic and random errors during the measurement of reflected radiation and albedo of the sea, carried out by us at an earlier date (ref. 1), as well as a series of additional investigations on the experimental ship "Gidrozond" in 1962, permitted the following conclusions relative to the measurement of reflected radiation: the albedo-meter must be installed on a Cardan's suspension at the end of the projected boom fixed at the bow of the ship and always turned towards the sun.

Measurements of the albedo at sea from the stern, as we shall see, are possible only when the ship is standing still. The albedo cannot be measured from the shipboard when moving or when standing still. The length of the boom on which the albedometer is installed must not be less than the elevation of the bow of the ship above the water. Then the error due to the shading effect of the ship will not exceed 3-4 percent for small values of $h_\odot$ or 6-7 percent for large values of $h_\odot$ (ref. 1).

In evaluating this error, it was assumed that the albedometer is always pointing towards the sun and that direct radiation is not shaded by anything.

On the expedition ships "A. I. Voyeykov" and "Gidrozond" we measured the albedo at various distances from the shipboard. The length of the boom on the expedition ship "A. I. Voyeykov" was 12 m, the height of the bow above water was 10 m. By means of a special device, the albedometer was moved along the entire boom to the board and back, and the albedo was measured along every meter on the boom.

The results of these measurements, carried out on the expedition ship "A. I. Voyeyekov," show that even for low altitudes of the sun the values of the albedo varied only when the albedometer was moved along the boom for a distance up to 10 m. Further extension of the albedometer along the boom did not produce any noticeable variations in the magnitude of the albedo.

Figure 4 shows the values of the albedo of the sea measured on the expedition ship "Gidrozond," at different distances from the shipboard. The length of the boom on the expedition ship "Gidrozond" was 3.5 m, the height of the bow above the water 2.0 m. The boom was gradually extended by the observer in such a way that the albedometer moved away from the shipboard. Measurements were made every 0.5 m.

As we can see from figure 4, the values of the albedo varied only when the albedometer was moved away from the shipboard up to a distance of 1.5-2.0 m. As it was moved further away, the values of the albedo generally remained constant.

Consequently, in carrying out actinometric measurements at sea, we may use the boom with a length equal to the height of the bow of the ship above water.

On the expedition ship "Gidrozond" we carried out special measurements while the ship was standing still and while it moved. During this time the

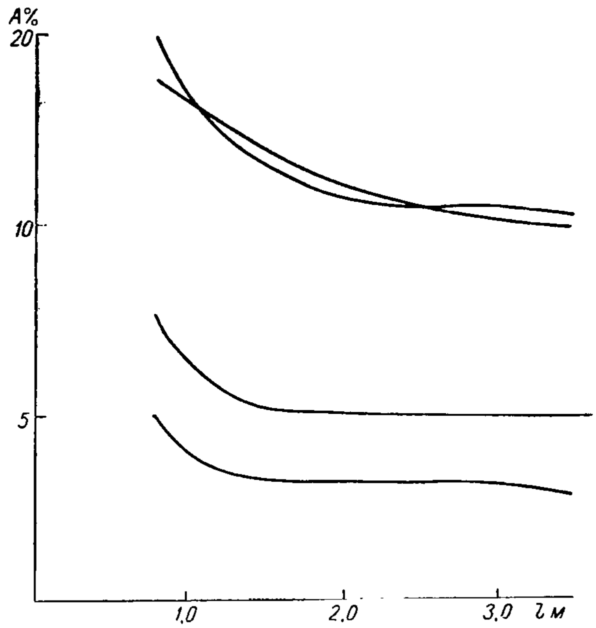

Figure 4. Values of albedo measured at different distance from shipboard.

boom with the albedometer was transferred from the bow to both boards and stern. Thus, the measurements of the values of the albedo at the bow of the ship, from the boards, and at the stern were carried out almost simultaneously.

TABLE 3.

Sept. 26
13 hr 00 min
$h_{\odot} = 42.0^{\circ}$
$0/0\odot^{2}$
waves 2-3 units
Sun on right board

A from bow, percent	A from right board, percent	A from left board, percent	A from stern percent
$\frac{2.3}{56.0} = 4.1$	$\frac{2.4}{57.2} = 4.2$	$\frac{2.2}{57.8} = 3.8$	$\frac{2.5}{58.5} = 4.3$

TABLE 4.

Sept. 27
16 hr 37 min
$h_{\odot} = 15.2^{\circ}$

5/0 Ci, $\odot^{0}$
waves 3-4 units

A from bow, percent	A from right board, percent	A from left board, percent	A from stern, percent
$\frac{5.0}{4.6} = 11.0$	$\frac{6.2}{4.7} = 13.2$	$\frac{7.0}{4.65} = 15.1$	$\frac{8.1}{4.8} = 16.9$

The results of the measurements when the ship was standing still are shown in Tables 3 and 4. They indicate that when measurements are made, the boom with the albedometer must be situated over the surface of the water which is illuminated by the sun. Otherwise, there will be local significant errors in the measured values of the albedo; e.g., when the sun shines from the stern and the measurements are made from the bow, the water surface whose reflection is measured is partially shaded.

We should note that if the measurement of albedo is carried out only when the ship is standing still, the boom with the albedometer may be installed at the bow and at the stern; however, in this case it is necessary to turn the ship so that the boom is facing the sun.

Tables 5-8 show the results of measuring the albedo during movement of the expedition ship "Gidrozond." On the basis of these we may make the following conclusions. During motion of the ship the measurement of reflected radiation and of the albedo may be made only from the bow, because at the boards and particularly near the stern a substantial area of the surface of water is disturbed by the motion of the ship and is covered by white foam, which substantially increases the value of the albedo of the water.

TABLE 5.

Sept. 28
9 hr 25 min
$h_{\odot} = 33.9^{\circ}$

10/10 Ac, Ci, Cu
waves 5-6 units

A from bow, percent	A from right board, percent (breakers, foam)	A from stern, percent: Above white foam	A from stern, percent: Over the breakers
$\frac{2.9}{34.3} = 8.4$	$\frac{8}{34.0} = 11.7$ (percent)	$\frac{5.7}{34.2} = 16.8$	$\frac{4.6}{34.2} = 13.5$

TABLE 6.

Sept. 28
9 hr 00 min
$h_{\odot} = 29.3$

$\boxed{10}/\boxed{10}$ Ac, Ci, Cu, $\odot^0$
waves 2 units

A from bow, percent	A from right board, percent (breakers, foam)
$\frac{3.2}{39.3} = 8.2$	$\frac{4.1}{38.9} = 10.5$

TABLE 7.

Sept. 27
11 hr 28 min
$h_{\odot} = 43.4^{\circ}$

10/10 Ci, Ac, Cu
waves 3-4 units

A from bow, percent	A from right board, percent: Beyond limits of foam	A from right board, percent: Over the foam
$\frac{2.7}{28.2} = 9.6$	$\frac{3.3}{28.0} = 11.8$	$\frac{6.5}{28.0} = 23.2$

TABLE 8.

Sept. 27
12 hr 15 min
$h_{\odot} = 44.5^{\circ}$

$\boxed{10}/\boxed{10}$ Ci, Ac, Cu, $\odot^0$
waves 4 units

A from bow, percent	A from right board, percent	A from stern, percent
$\frac{2.9}{46.3} = 6.2$	$\frac{3.4}{46.5} = 7.3$	$\frac{5.2}{46.7} = 11.1$

Because of high wind velocities it is possible for the Cardan's suspension to be deflected from the vertical position. In measuring reflected radiation, it is desirable to use a "wind shield," analogous to the "windshield" for the pyranometer, attached on the mast of the ship when measuring total radiation. However, in this case a headpiece for the Cardan's suspension is fabricated from a light material (cork, foam plastics) and is placed at the upper part of the Cardan's tube.

In measuring the reflected radiation of a rough sea, it is possible that sea water will fall on the glass of the albedometer, and it is also possible for the glass to sweat from the inside. In connection with this, a special investigation was made to determine the variation in the reading of the albedometer when it was sprayed (Table 9).

From Table 9 we can see that when drops of water fall on the glass of the albedometer with the sensing surface facing downward, the values of reflected radiation and of the albedo increase on the average by 10-15 percent.

TABLE 9.

Date	Time, hrs min	$h_\odot$ degrees	Cloudiness	Q cal/cm^2/min	R cal/cm^2/min	R_1 cal/cm^2/min	A percent	A_1 percent	$\frac{A-A_1}{A}$ percent
Oct 4	10 29	36.8	4/4 Cu	0.603	0.039	0.046	6.4	7.6	19
Oct 4	10 35	37.3	4/4 Cu, $\odot^0$	0.600	0.037	0.040	6.2	6.7	8
Oct 4	12 17	40.8	3/3 Cu, $\odot^2$	1.070	0.062	0.069	5.7	6.4	12
Oct 4	12 47	39.6	10/10 Ci, Cu	0.238	0.025	0.026	10.4	11.1	7
Oct 4	16 13	14.8	9/9 Cu, $\odot^0$	0.331	0.032	0.037	9.6	11.2	17
Oct 4	16 47	10.7	6/6 Cu,	0.178	0.012	0.014	6.8	7.8	15
Oct 4	16 53	9.1	6/6 Cu. Sun in the cloud behind a mountain	0.109	0.0053	0.0070	4.9	6.4	30
Oct 5	11 10	38.7	0/0 $\odot^2$	1.2	0.068	0.072	5.7	6.0	5
Oct 6	7 15	18.4	0/0 $\odot^2$	0.385	0.075	0.079	19.5	20.6	6

Note: A is the value of the albedo measured with a dry albedometer; A_1 is the value of the albedo measured after the albedometer has been sprayed.

Consequently, in measuring reflected radiation at sea, it is necessary systematically to check the condition of the glass cover of the albedometer and to wipe it dry with a soft cloth when it is sprayed.

The albedometer must be in a strictly horizontal position, because any deviation from a horizontal position leads to substantial errors in the measured values of the albedo (ref. 1).

In view of the fact that with the GSA-1 galvanometer the errors in the measurement of the albedo were high, and when the ship rolls may reach 40-50 percent, it is recommended that the M-91 galvanometer or the EPP-09 electronic potentiometer be used. To provide for maximum accuracy of measurements, not less than 6 readings should be taken with the galvanometer.

If the recommendations we have made are followed, the values of the albedo at sea may be measured with an error not exceeding 10 percent for large values of $h_{\odot}$ or 20-25 percent for small values of $h_{\odot}$.

Radiation Balance

Radiation balance is the basic factor affecting the formation of a climate. Therefore, its investigation is most significant. At the same time, measurement of the radiation balance of the sea from ships becomes difficult due to the effect of the ship's hull, the horizontal and vertical air flow around the balance meter, the spraying of the sensing surfaces by water, etc.

The questions of measuring the radiation balance at sea are discussed thoroughly in the article by N. Ye. Ter-Markaryants and B. L. Grishchenko (ref. 2) (contained in the present volume). In this connection we shall limit ourselves to the presentation of basic practical recommendations necessary for measuring radiation balance at sea.

1. Radiation balance is measured by means of a thermoelectric balance meter, installed on the same boom as the albedometer.

2. To eliminate the effect of wind, the sensing surfaces of the balance meter are covered with a polyethylene film with a clearance between the sensing surface and the film equal to 2 mm.

The film is stretched between 2 rings which work like supports (each balance meter requires 4 rings). The rings with the polyethylene films are attached to the balance meter with special lamellar clamps.

It is most rational to use a flat filter because it is simpler to make and because it has a longer life under operating conditions compared with other forms of filters.

3. In measuring the radiation balance at sea, the balance meter must not be shaded from direct solar radiation.

4. The readings of the balance-meters are corrected, taking into account variation in the sensitivity of the balance meter as a function of the angle of incidence of radiation. It is particularly important to introduce an angular correction when the altitudes of the sun above the horizon are less than 40°.

5. In measuring the longwave balance, balance meters calibrated not for direct solar radiation, but for longwave radiation must be used, otherwise it is necessary to introduce a corresponding correction for reading the balance-meter.

6. When the balance meter is sprayed with sea water or when raindrops or dew fall on its sensing surfaces, measurement of the radiation balance should be stopped, the sensing surfaces of the balance meter covered with polyethylene film should be wiped dry, and, if the film sweats from the inside, the balance meter should be dried; measurements can then continue.

7. To measure radiation balance at sea, it is necessary to use the M-91 galvanometer or the EPP-09 electronic potentiometer.

8. The balance meter must be kept in a strictly horizontal position at all times, and the polyethylene filters must be clean.

If these directions are followed, the radiation balance at sea can be measured with an error not exceeding 10-15 percent for large values of $h_{\odot}$ and 30 percent for small values of $h_{\odot}$.

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